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(NACA-RM-L58G31) SOME NOTES ON THE PROBABLE DAMAGE TO AN INTERCONTINENTAL-BALLISTIC-MISSILE WARHEAD FOLLOWING PUNCTURE OF THE HEAT SHIELD H.K. Strass, et al (NASA) 28 Sep. 1958 25 p

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SOME NOTES ON THE PROBABLE DAMAGE TO AN INTERCONTINENTAL-BALLISTIC-MISSILE WARHEAD FOLLOWING PUNCTURE OF THE HEAT SHIELD

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

SOME NOTES ON THE PROBABLE DAMAGE TO AN INTERCONTINENTAL-BALLISTIC-MISSILE WARHEAD FOLLOWING PUNCTURE OF THE HEAT SHIELD*

By H. K. Strass and V. M. Goodman

SUMMARY

A brief study of some effects following puncture of the heat shield of a possible intercontinental-ballistic-missile warhead by small projectiles has been conducted. Simplified calculations suggest that there is little probability of inflicting massive damage to the warhead as a result of the pressurization and heating which would occur as a result of air flow through the puncture into the interior of the warhead. An experimental study conducted in an electric-arc powered air jet at a stagnation temperature of approximately 6,000° K indicates that considerable local damage to internal components located within 3 inches of the heat shield may occur as a result of impingement of the jet of hot air forced through the puncture in the heat shield under certain conditions of flight. The possibility exists that the projectile after penetration of the heat shield would have sufficient energy to inflict considerable mechanical damage to the interior of the warhead either from the projectile itself or by virtue of back spall ejected from the heat shield.

INTRODUCTION

A possible countermeasure to the intercontinental ballistic missile (ICBM) may exist in interposing a screen of small metal projectiles in the path of the warhead in the manner suggested by Charters in reference 1. Charters showed that the velocity of an ICBM warhead is sufficient to cause complete penetration of the heat shield if the warhead were to strike one of these projectiles. The velocity of the warhead at reentry is sufficiently high that the velocity of the metal projectiles is of little consequence. A brief exploratory analytical and

experimental study of some of the effects of penetration of the heat shield of a warhead was undertaken and the information gathered to date has been collected for presentation in this paper. The experimental portion of this program was conducted in the electric-arc powered air jet of the Langley Structures Research Division.

SYMBOLS

g	acceleration due to gravity, 32.2 ft/sec^2
H_T	total enthalpy, Btu
M	Mach number
P	pressure at stagnation point, lb/sq ft
P_i	pressure within warhead, lb/sq ft
t	time after reentry, sec (Reentry into the atmosphere is assumed to occur when warhead reaches an altitude of 250,000 feet)
T	temperature of air at stagnation point, ^oK
T_i	temperature within warhead, ^oK
V	velocity, ft/sec
h	altitude, ft
ρ	density of air, slugs/cu ft

STUDY OF DAMAGE POTENTIAL

Approximate Analysis of General Damage

Reference 1 considers projectiles of two shapes: rods and spheres. The rods were shown to give greater penetration for the same weight projectile as the spheres but must strike the warhead end-on; thereby, additional complication in the design and construction of the defense missile was required. Depending upon the choice of projectile, the resulting holes in the nose may range from a minimum of $\frac{1}{8}$ inch in

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diameter to 1 inch or larger in diameter. The damage to the contents of the warhead resulting from penetration of the heat shield is difficult to assess in detail as it would depend on the location of the puncture and whether particularly vital equipment was installed in the immediate vicinity of the air blast which would be forced through the hole during certain portions of the reentry trajectory. Detailed investigation of damage of this nature was considered to be beyond the scope of this study.

Potential destruction of the warhead might result from destructive pressurization or from general deterioration of delicate equipment as a result of being enveloped in superheated air.

Simplified calculations were made to ascertain the probable magnitude of internal pressure to be expected within a warhead following penetration of the heat shield by small projectiles striking near the stagnation point. Holes of $\frac{1}{4}$ inch, $\frac{1}{2}$ inch, and 1 inch in diameter were considered and were assumed to have an orifice coefficient of 0.6 for purposes of calculating the weight flow of air through the holes by employing the relation given in reference 2. About one-fourth of the total warhead volume was assumed to be available for pressurization (in this case, 19 cu ft). The assumed reentry time history is presented in figure 1 and the resulting properties of the air at the stagnation point as obtained from reference 3 are given in figure 2.

In order to simplify the calculations they were performed by using a step-by-step process and by assuming that prior to penetration of the heat shield the air within the warhead was at standard sea-level conditions. The properties of the air within the warhead after penetration were determined from the Mollier diagram given in reference 3 which assumes an adiabatic, constant-enthalpy expansion process. The resulting calculated pressures and temperatures of the air within the warhead are probably much higher and the enthalpy much lower than would actually occur, particularly during the initial portion of the reentry, as the mass of air passed into the warhead is very small and considerable heat transfer must take place as this small quantity of air comes in contact with the cool internal surfaces of the warhead.

The results of the calculations are presented in figure 3 for four cases which are as follows:

I. $\frac{1}{4}$- inch-diameter puncture at instant of atmospheric reentry ($t = 0$)

II. $\frac{1}{2}$-inch-diameter puncture at instant of atmospheric reentry (t = 0)

III. $\frac{1}{2}$-inch-diameter puncture at time when stagnation pressure is equal to pressure within warhead (t ≈ 13 seconds)

IV. 1-inch-diameter puncture prior to reentry so that pressure within warhead is zero at reentry.

The most significant fact regarding cases I and II is that air will flow out of the hole for the first 12 to 13 seconds of the reentry trajectory and will probably result in a slight cooling effect on the skin in the vicinity of the puncture. The calculations for case II indicate that approximately one-third of the air initially contained within the warhead will have been exhausted by the time pressure equalization across the hole is established. For comparison, the internal pressure for cases I, II, and III were also computed by assuming that the mass of air exchanged through the hole was small relative to that initially contained within the warhead. As a consequence, mixing of this small air mass with the larger air mass and the large area of the metallic surfaces exposed to the air within the warhead must contribute appreciably toward temperature stabilization of the air within the warhead. For simplicity, the calculations were performed by assuming that the temperature of the air within the warhead remained constant. The results of these calculations are presented for cases I, II, and III (as a dashed line in fig. 3) and show negligible pressure changes within the warhead. The true response of the internal environment of the warhead will lie somewhere between the extremes of possible behavior represented by these conditions.

The maximum input of heated air would occur if the warhead were punctured sufficiently in advance of atmospheric reentry that for all practical purposes the warhead is totally evacuated prior to reentry. Case IV presents the calculations made for a 1-inch-diameter puncture made far in advance of reentry. This hole size probably is somewhere near the upper limit in practically attainable hole size. The calculated pressure lagged only slightly behind the pressure at the stagnation point and indicates that little is to be gained by striving for larger diameter punctures in the heat shield other than increased mechanical damage from high-speed particles. The total enthalpy of the air within the warhead reaches a maximum near the end of the eighteenth second and is estimated to be about 1,400 Btu for the volume assumed (19 cu ft). This is not a sufficient quantity of heat to cause damage on a general scale even if all this heat could be transferred to the interior of the warhead.

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The calculations were terminated at 22 seconds because at this time the warhead will have approached to within 80,000 feet of the ground and continued pressurization and heating at the rate calculated does not seem likely to cause damage prior to arriving within lethal range of the target.

The results presented here indicate that the pressurization and heating resulting from small holes at the stagnation point offers little probability of inflicting general damage to the warhead. Examination of figure 2 shows that the maximum pressure available occurs at about 18 seconds and it is debatable whether even this 4 atmospheres of pressurization would be destructive. Certainly, initial pressurization of the warhead to over 4 atmospheres would be an effective countermeasure against damage of this nature.

Experimental Study of Local Damage

The previous discussion suggests that destruction of the warhead of an ICBM as a result of general damage from pressure or heating of the interior following puncture of the heat shield by a small projectile is unlikely. This result does not rule out the possibility of destruction or deactivation of the warhead resulting from local damage to delicate components caused by the impingement of the hot jet of air forced through the hole in the heat shield under certain conditions of flight. The specific enthalpy of the air in the stagnation region at reentry speeds is enormous and the heat energy this represents will certainly be capable of causing much local destruction.

Models and technique.- In order to investigate the local destructive effects following puncture of the heat shield, high-speed motion-picture studies (approximately 880 frames per second) were made of a series of flat-faced copper models tested in an air-stabilized arc jet which is equipped with a $\frac{1}{2}$-inch diameter, Mach 2 nozzle. Accurate knowledge regarding test conditions in the arc jet does not yet exist although calculations indicate that the stagnation temperature was approximately 6,000° K. The stagnation pressure during these tests averaged roughly 16,000 pounds per square foot absolute. A complete description of the arc jet is given in reference 4. The resulting stagnation pressure on the face of the models under these circumstances was computed to be about 11,500 pounds per square foot absolute and the weight density of the air was about 0.014 pound per cubic foot, the Mollier diagram of reference 3 being assumed to be applicable. These conditions are slightly more severe than the maximum values encountered during reentry.

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The models that were tested are described in the sketch presented as figure 4 and table I. Photographs of typical models are presented as figure 5. The models were intended to simulate a portion near the stagnation region of a copper heat shield of a ICBM warhead. Holes were drilled through the copper models simulating the punctures resulting from projectile impact. The probable extent of the destructive region behind the hole was determined by metal plates mounted on the model support normal to the axis of the hole. Figure 6 shows a typical arrangement of model and metal plates and the method of mounting the assembly in the arc jet. The metal plates in one of the tests were equipped with thermocouples in order to obtain some idea as to the probable local heat input to be expected by objects subject to impingement of the air jet issuing inward from the puncture.

General observations applicable to all models.- The average length of time the models were exposed to the arc jet was approximately 4.5 to 5.0 seconds. The usual procedure was to insert the models into the jet about 1.5 seconds after the jet was started. The motion-picture studies showed certain general characteristics applicable to all of the tests. A luminous supersonic jet was emitted from the back face of the models which generally extended to about 3 inches in length. One inch from the back face of the model the jet appeared to be about twice the diameter of the hole in the model.

Craters, very roughly sperical in shape and about 1 inch in diameter, were gouged out of the front faces of the models by the action of the jet. Considerable variation in the depth of these craters was evident for the different models. The photograph presented as figure 7 shows very clearly the results of jet action on the faces of these models. The deep holes gouged into the faces of the models caused part of the arc jet to be turned back on itself during the latter portion of the tests and as a result there was some minor damage to equipment located in the vicinity of the nozzle. The cratering action of the jet is believed to be a phenomenon peculiar to the method of testing and is not associated with the actual case. The large size of the model relative to the jet prevents flow around the model and tends to concentrate the heating action of the jet to a relatively small region on the face. The presence of the craters is not believed to have any appreciable effect upon the flow through the model.

Whereas the faces of the models were eroded badly by the arc jet, the interior sides of the holes drilled through the models showed no evidence of damage whatsoever and thus indicated little possibility of enlargement of holes made through the heat shield of an ICBM warhead as a result of projectile impact. Occasionally, during each test, the jet issuing from the back face of the model was observed to die out completely and then reappear following a shower of incandescent globules

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of molten copper. Evidently, a temporary blockage existed at the entrance of the hole which was quickly blown away. The apparent blockage was always of extremely short duration.

Observations pertaining to individual models.- No essential characteristics different from those mentioned in the previous discussion were observed in models 1 and 2. Model 2 was modified by beveling the edge of the front face in an attempt to reduce spreading of the jet at the face of the model. This was successful during the early portion of the test, but the cratering action of the arc jet completely offset any beneficial effects that beveling had and subsequent models were not modified.

A $\frac{1}{4}$-inch-diameter hole was drilled through model 3 and a 0.061-inch-thick aluminum-alloy plate was mounted normal to the axis of the hole 2 inches from the back face of the model. The jet issuing from the model was observed to cut through the aluminum plate approximately 2 seconds after the start of the test and a hole of about $1\frac{1}{8}$ inches in diameter resulted. A photograph of the model and plate after the test is presented as figure 8. The circular cut-out in one side of the aluminum plate was made prior to the time the model swung into the arc jet. No change in the length of the jet issuing from the back face of this model was observed as compared to the preceding models with $\frac{1}{8}$ inch holes.

Model 4 was similar to model 1 but was made one-half the length of the previous models. A 0.032-inch stainless-steel plate was mounted 4 inches from the back of the model. The reduction in model length had no apparent effect upon the character of the jet issuing from the model. No visible damage to the stainless steel plate was observed. The plate was spattered with molten copper from the model as can be seen quite clearly in the photograph presented as figure 9.

Two 0.061-inch aluminum-alloy plates were mounted at $1\frac{1}{2}$ and 3 inches from the back face of model 5 which in other respects was identical to model 1. No recorded data were obtained regarding this test because of equipment failure. The hole in the first plate was approximately $\frac{3}{4}$ inch in diameter and about $\frac{5}{8}$ inch in diameter in the second plate. Figure 10 presents a photograph of model 5 and plates after test.

Two 0.032-inch stainless-steel plates were mounted behind the back face of model 6 in a manner identical to model 5. Figure 11 is a

[redacted]

photograph of model 6 after the test. The plate nearest model 6 was burned through approximately 3.3 seconds after the start of the test. The second plate was penetrated about one second later. The holes in the plates were about $\frac{1}{2}$ inch in diameter in the first plate and $\frac{3}{8}$ inch in diameter in the second plate. Chromel-alumel thermocouples were installed in the center of each plate on the side farthest from the model. Time histories of the measured plate temperatures are given in figure 12. The plates were subjected to moderate heating after the arc jet was turned on and prior to insertion of the model in the arc jet as a result of jet expansion. The plate farthest from the models showed the greatest temperature rise (about 300° F) prior to start of the test. The maximum local heat input to the plates in the region of jet impingement was about 190 Btu per square foot per second for the first plate and about 240 Btu per square foot per second for the second plate. The difference in the heating values for the two plates probably results from the fact that the thermocouples were not in thermally comparable locations relative to the jet.

As previously noted, the average length of time the models were exposed to the arc jet was approximately 4.5 to 5 seconds. In the actual case, the warhead would be subjected to a much longer period of heating but varying greatly in severity. The present tests indicate that only a few seconds of heating at the maximum rate are necessary to cut through thin metal plates symbolizing internal hardware. Definite conclusions regarding damage to actual internal components are beyond the scope of this paper but it seems reasonable to infer that under certain conditions of flight internal components located within 3 inches of the heat shield may suffer considerable local damage as a result of impingement of the jet of hot air forced through a puncture in the heat shield.

Implications of Recent Impact Studies

Some recent impact studies made by the Langley Pilotless Aircraft Research Division (ref. 5) suggest that the values of penetration given by Charters (ref. 1) may be conservative and as a result greater damage to the heat shield of an ICBM warhead may be incurred as a result of impact with a small projectile than is inferred by the previous discussion in this paper. The values of penetration given in reference 1 were based upon data obtained from projectiles impacting at speeds up to 10,000 feet per second. The data of reference 4 were obtained from impacts at speeds up to 11,500 feet per second. Both sets of data were obtained by measuring the penetration in very thick solids where the wall thicknesses were appreciably greater than the depths of penetration (semi-infinite solids). In addition, if complete penetration of the warhead could be achieved, this would vent the interior to the near

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vacuum at the base and would further increase the mass flow of hot air into the interior for a longer portion of the flight.

CONCLUDING REMARKS

A brief study of some effects following puncture of the heat shield of an intercontinental-ballistic-missile warhead by small projectiles has been conducted. Simplified calculations suggest that there is little probability of inflicting massive damage to the warhead as a result of the pressurization and heating which would occur as a result of air flow through the puncture into the interior of the warhead. An experimental study conducted in the air-stabilized arc jet of the Langley Structures Research Division indicates that considerable local damage to internal components located within 3 inches of the heat shield may occur as a result of impingement of the jet of hot air forced through the puncture in the heat shield under certain conditions of flight. The possibility exists that the projectile after penetration of the heat shield would have sufficient energy to inflict considerable mechanical damage to the interior of the warhead either from the projectile itself or by virtue of back spall ejected from the heat shield. Further and more detailed research into this problem is a necessity. Particular attention should be given to the evaluation of the probability of destruction or deactivation of the warhead when the damage following puncture of the heat shield is limited to the immediate vicinity of the puncture.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 15, 1958.

[redacted]

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1. Charters, A. C.: Some Preliminary Experiments on High-Speed Impact and Their Application to an Anti-ICBM Weapons System. Presented at Naval Ordnance Laboratory, Oct. 23, 1957.

2. Perry, John H., ed.: Chemical Engineers' Handbook. Third ed., McGraw-Hill Book Co., Inc., 1950.

3. Feldman, Saul: Hypersonic Gas Dynamic Charts for Equilibrium Air. AVCO Res. Lab., Jan. 1957.

4. Kotanchik, Joseph N.: The Use of High-Intensity Arcs in Arc-Image Furnaces and Electric-Arc-Powered Jets. High-Intensity-Arc Symposium, Control Res. Lab., The Carborundum Co. (Niagara Falls, N.Y.) June 13-14, 1957. (Sponsored by WADC and the Carborundum Co.)

5. Kinard, William H., and Lambert, C. H., Jr.: An Investigation of the Effect of Target Temperature on Projectile Penetration and Cratering. NACA RM L58E14, 1958.

[redacted]

TABLE I

ARC-JET TESTS ON SIMULATED-DAMAGE MODELS

Test	Model dimensions		Hole diameter, in.	Target plates	Target plate spacing from back of model, in.	Instrumentation	
	Diameter, in.	Length, in.				Motion pictures	Thermocouples
1	2	2	1/8	None	---	Black and white	None
2	2	2	1/8	None	---	Black and white	None
3	2	2	1/4	One 0.06-inch aluminum alloy	3.0	Black and white, color	None
4	2	1	1/8	One 0.03-inch stainless steel	4.0	Black and white, color	
5	2	2	1/8	Two 0.06-inch aluminum alloy	1.5 3.0	None None	None
6	2	2	1/8	Two 0.03-inch stainless steel	1.5 3.0	Black and white, color	1 at center of each target plate

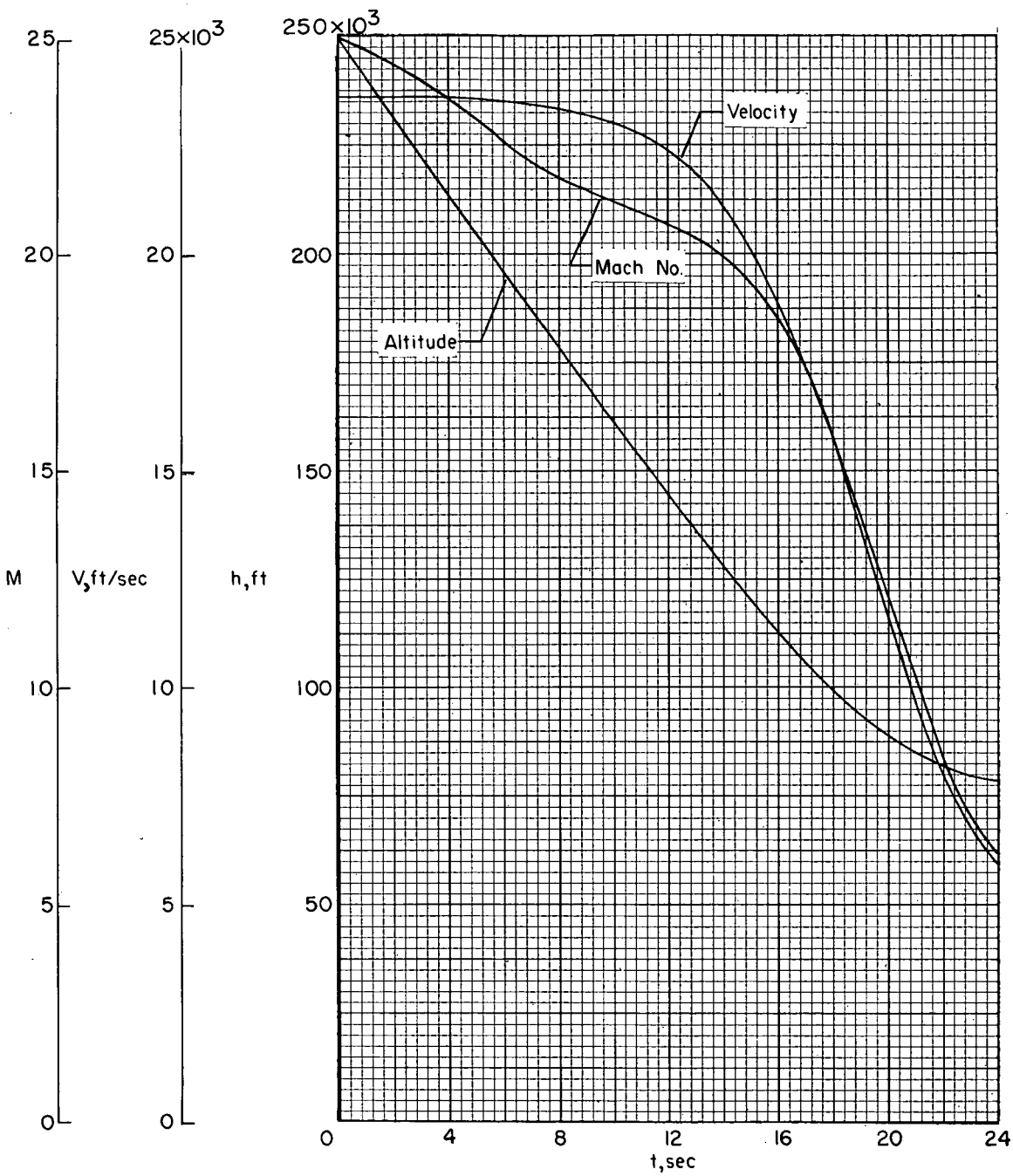


Figure 1.- Velocity, Mach number, and altitude time histories for time after reentry at an altitude of 250,000 feet.

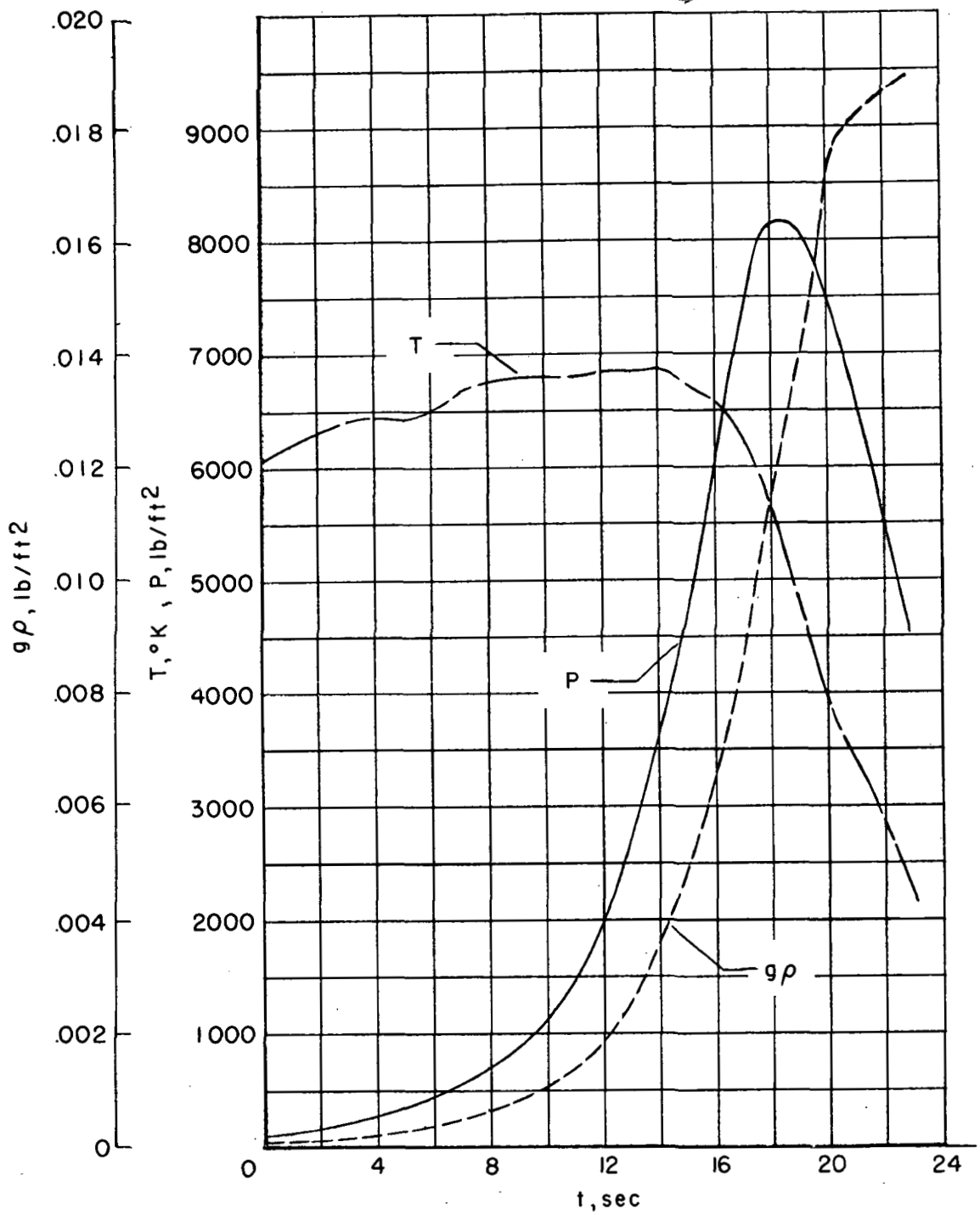
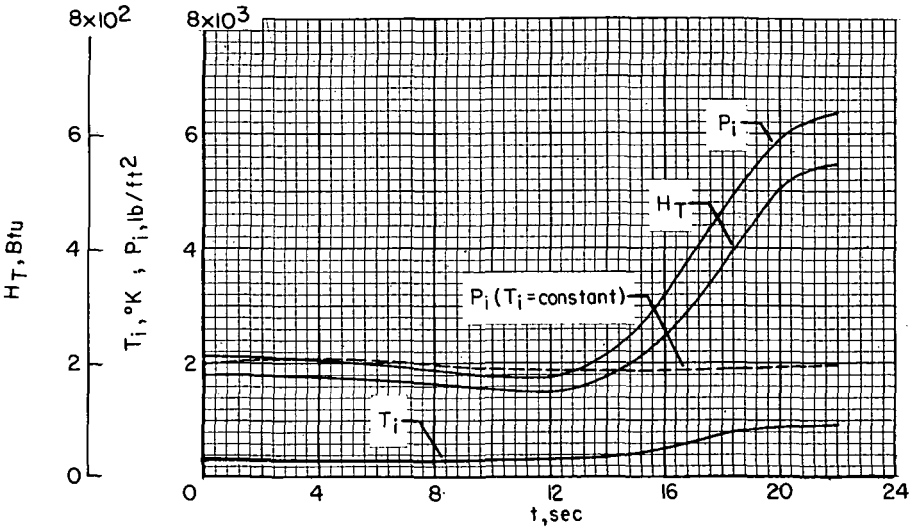
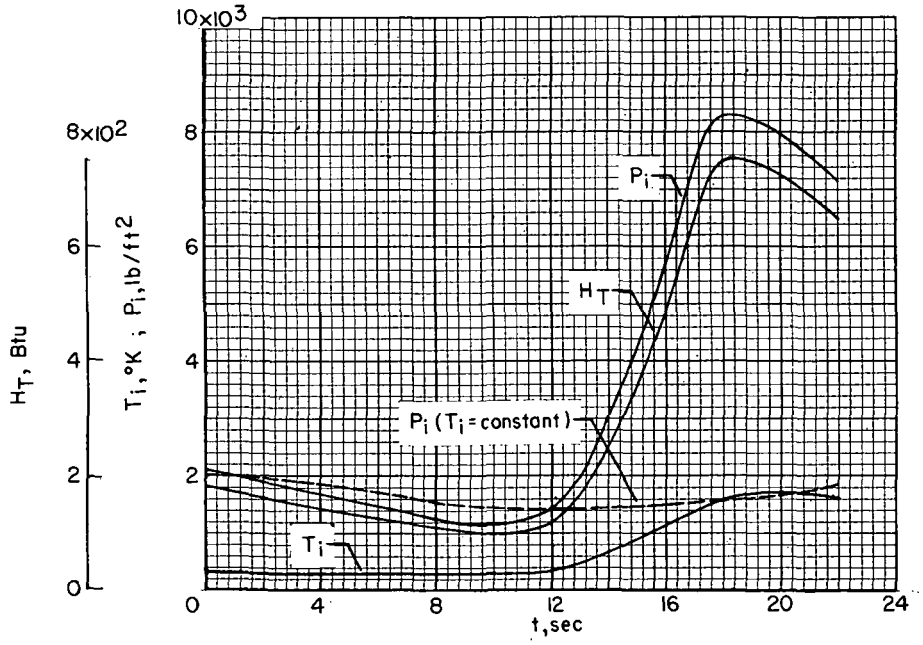


Figure 2.- Variation of stagnation-point air properties with time after reentry of an ICBM warhead.

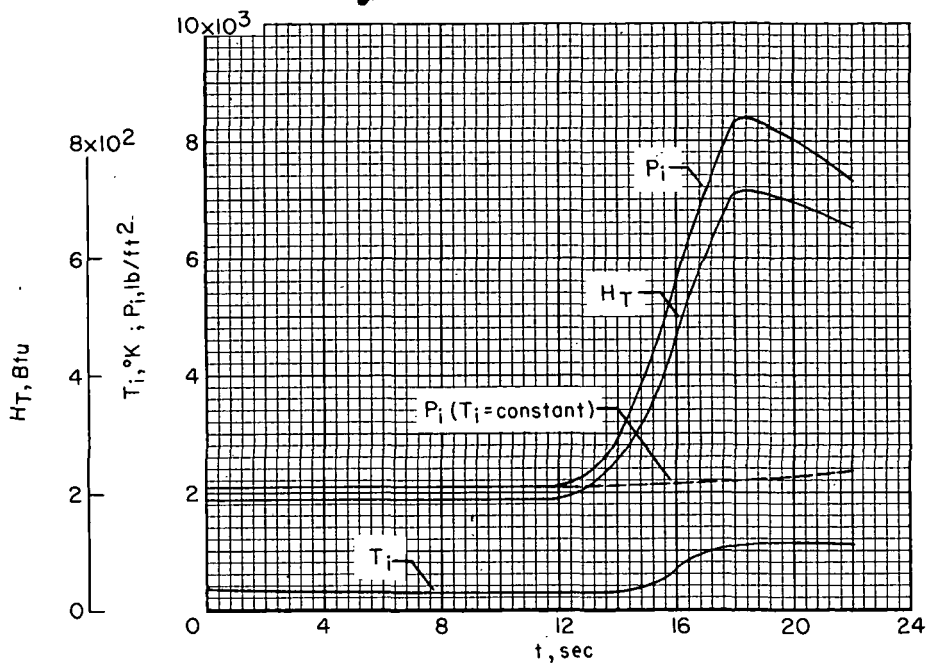


(a) Case I - $\frac{1}{4}$ - inch-diameter puncture at reentry.

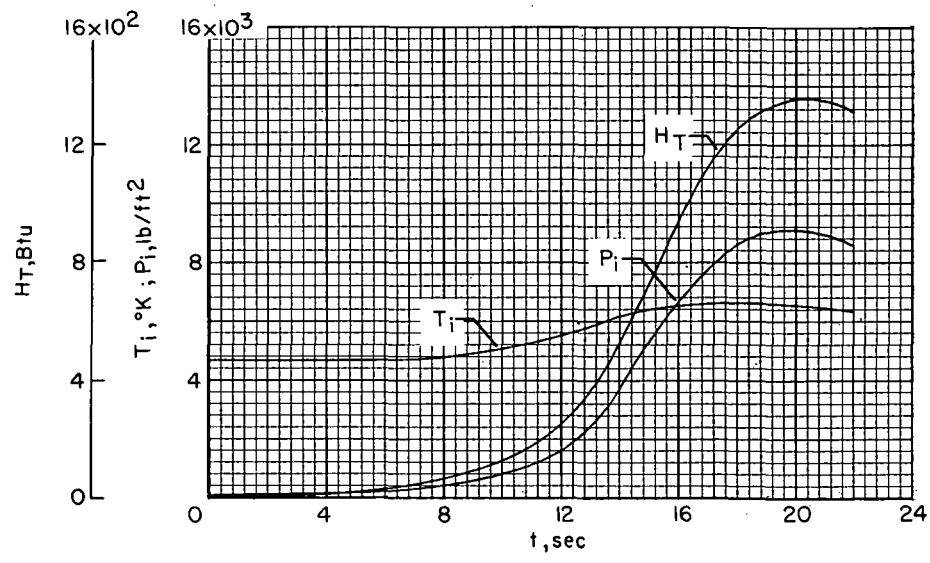


(b) Case II - $\frac{1}{2}$ - inch-diameter puncture at reentry.

Figure 3.- Variation of air properties within warhead with time after reentry for several hole sizes in the heat shield at the stagnation point.



(c) Case III - $\frac{1}{2}$-inch-diameter puncture when stagnation pressure equals internal pressure.



(d) Case IV - 1-inch-diameter puncture prior to reentry.

Figure 3.- Concluded.

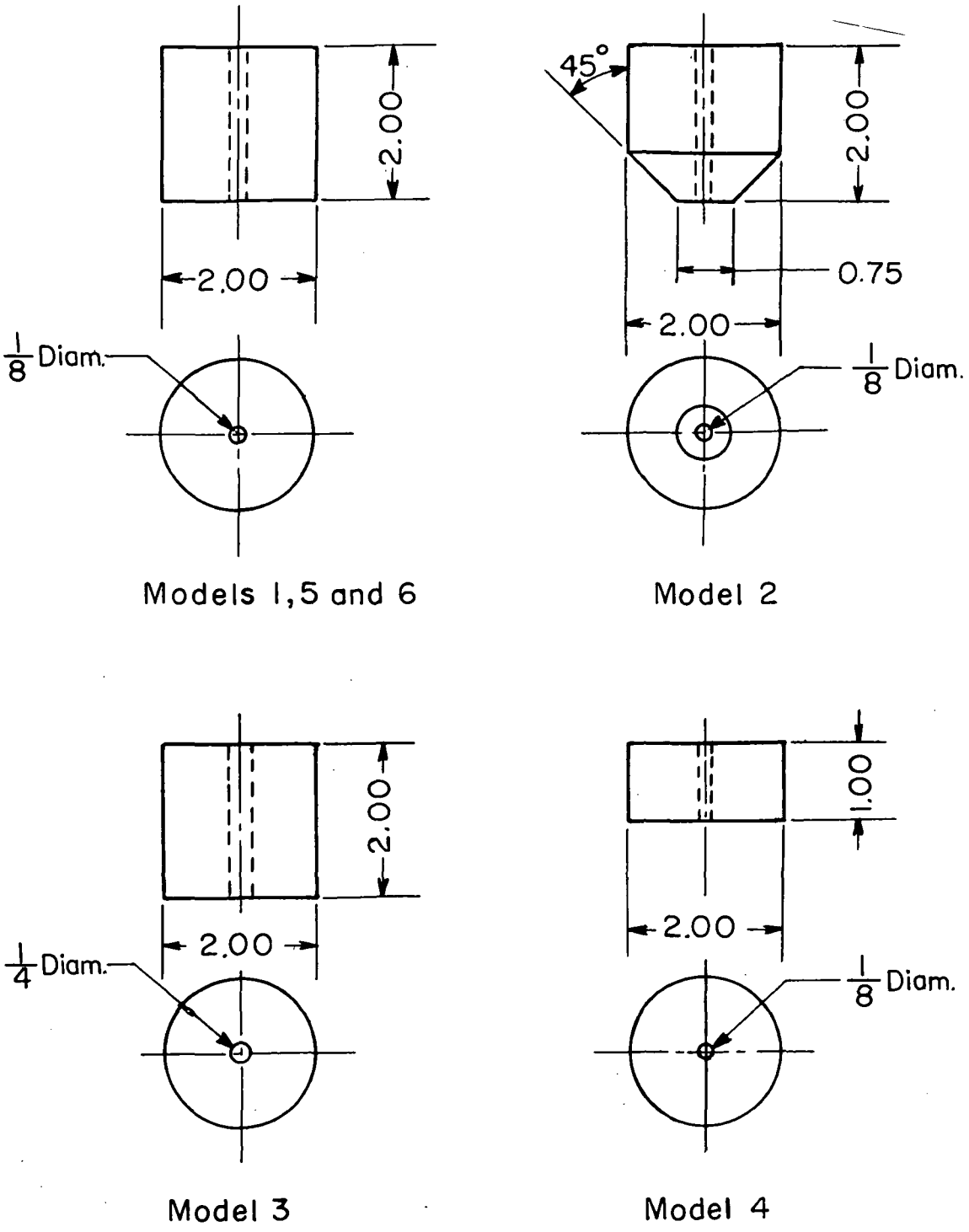
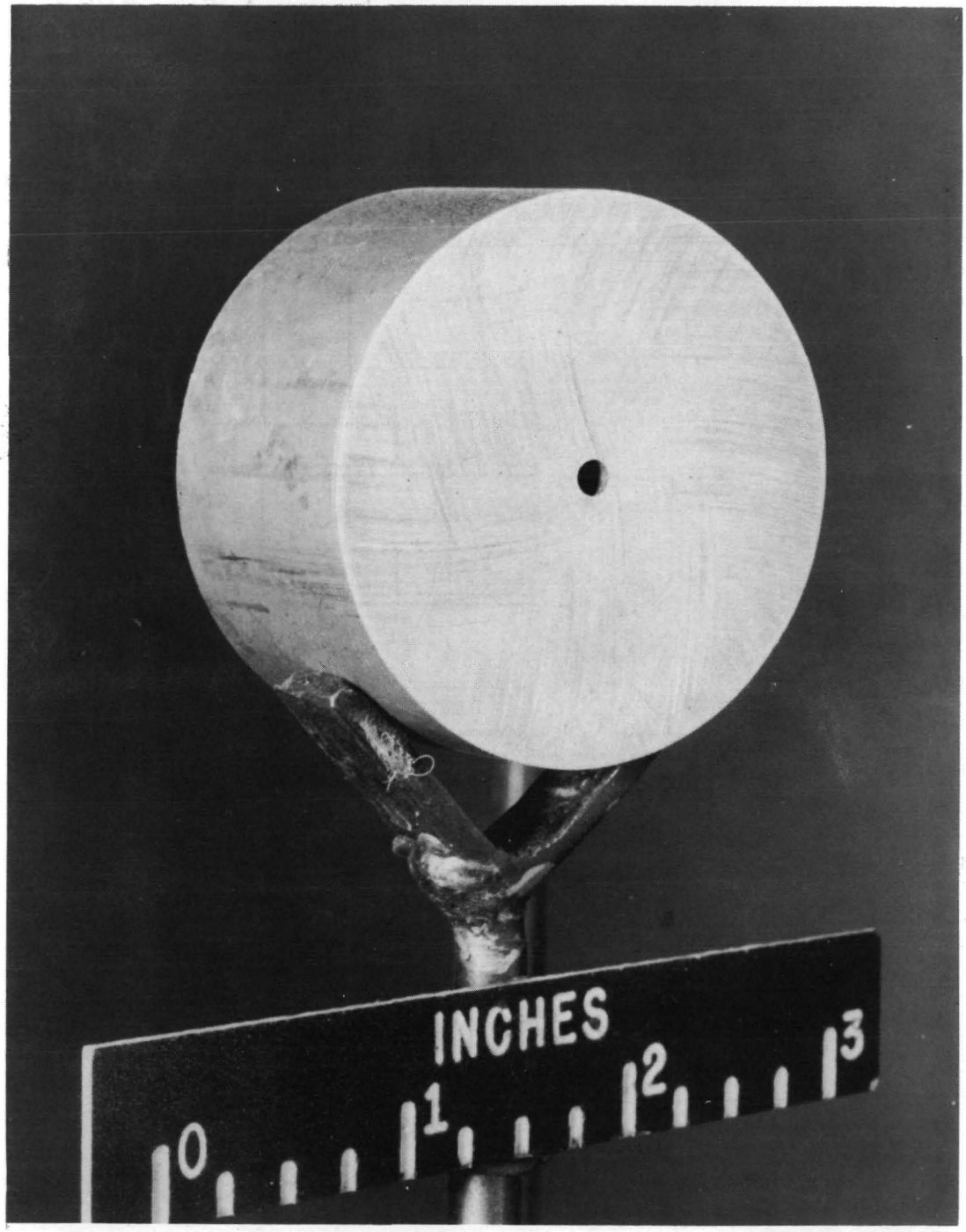


Figure 4.- Details of test models. All dimensions are in inches.

(a) Model 3. L-57-4866

Figure 5.- Typical damage models.



(b) Model 4. L-57-4864

Figure 5.- Concluded.

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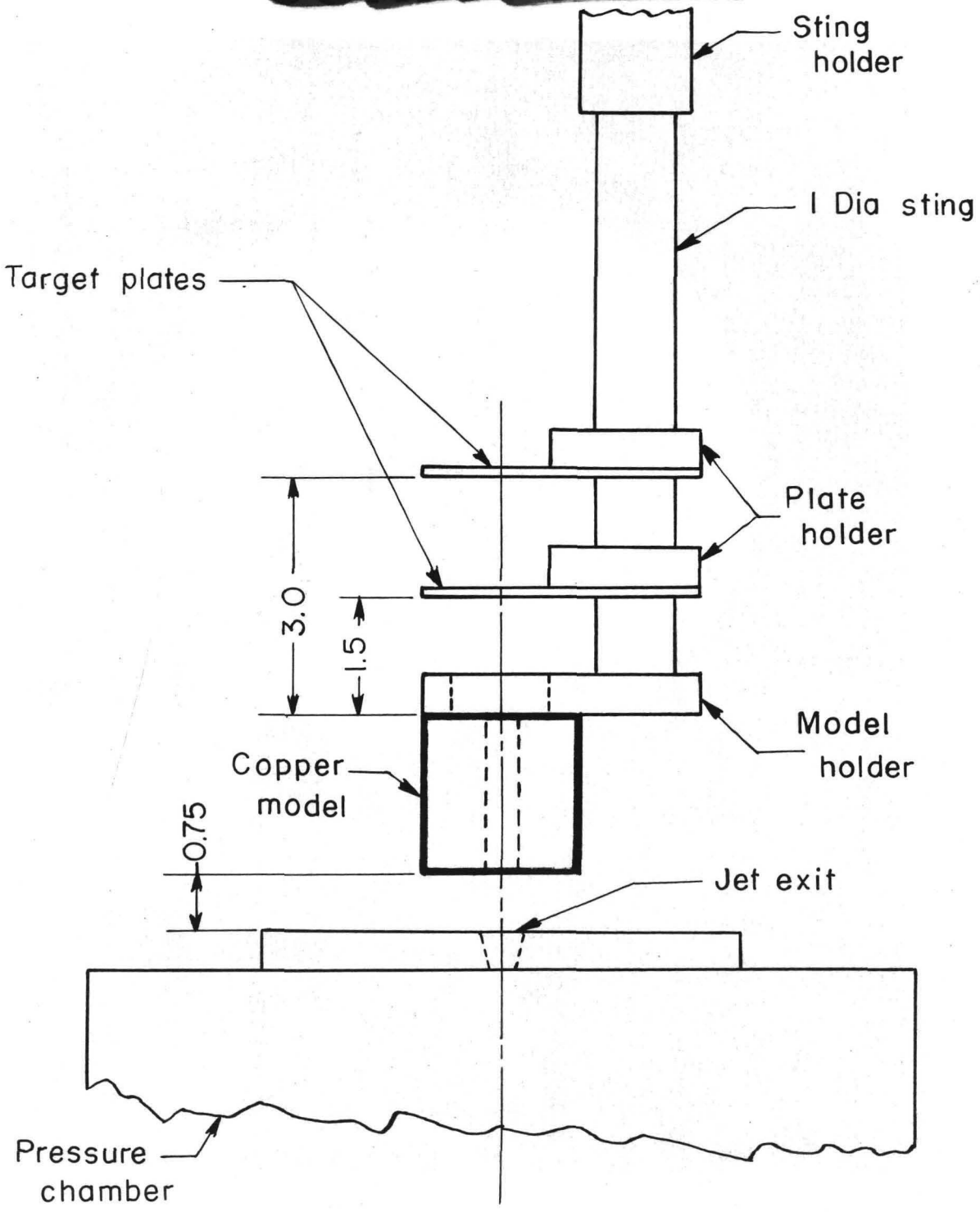

Figure 6.- Installation of typical model and target plates in arc jet. All dimensions are in inches.

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Figure 7.- Front faces of models after test. L-57-5064

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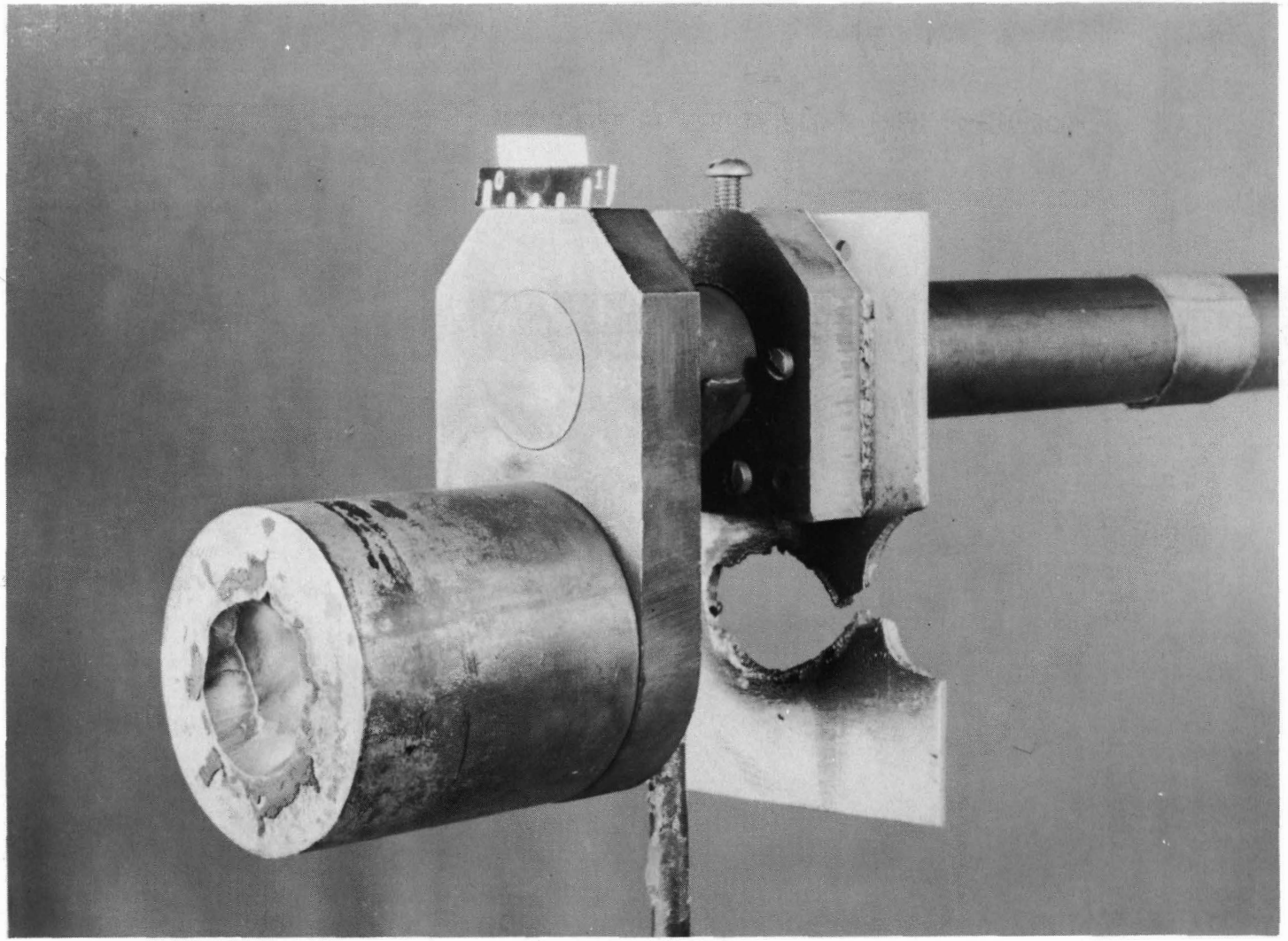

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Figure 8.- Model 3 and 0.06-inch aluminum plate after test.

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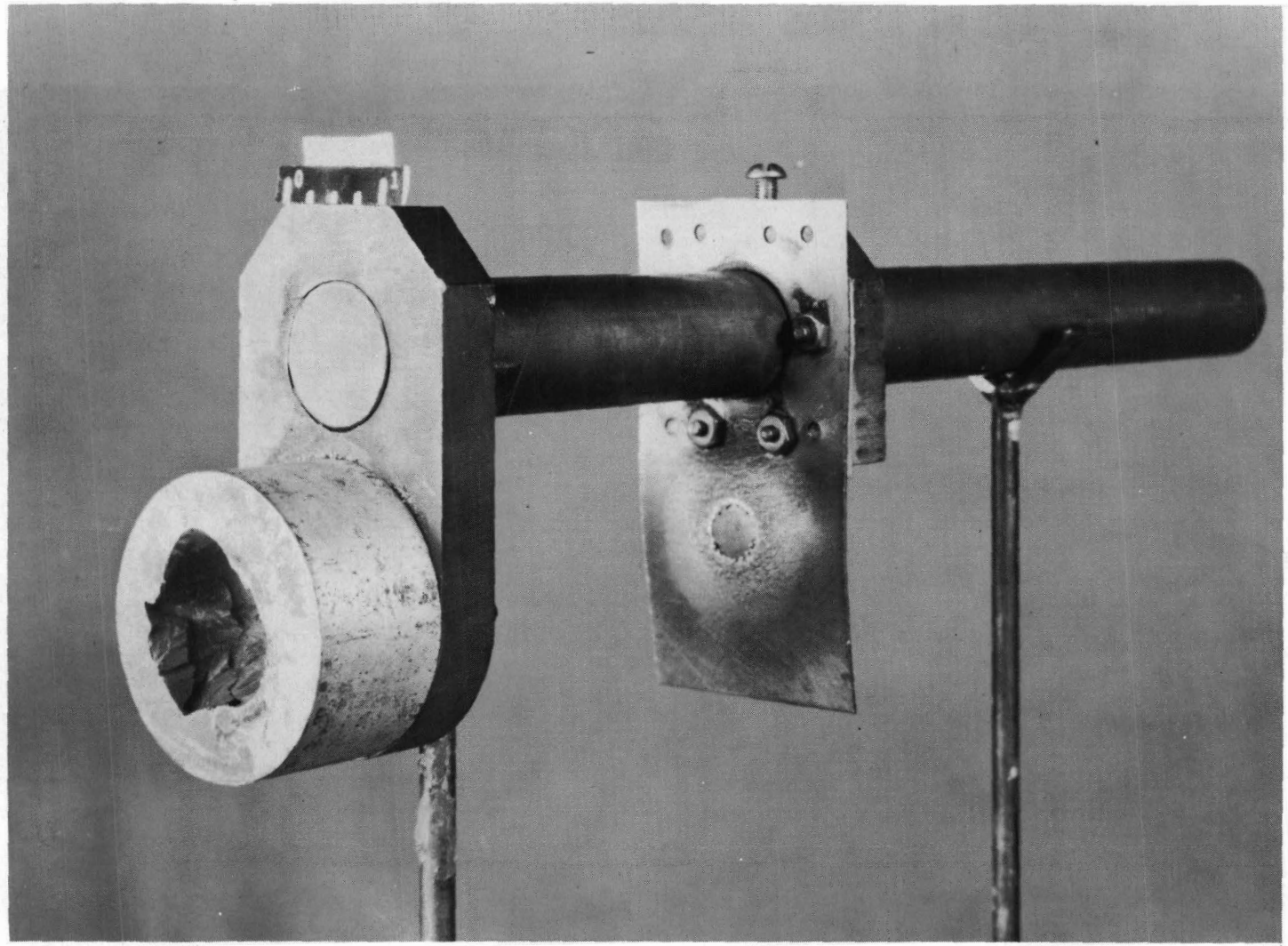

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Figure 9.- Model 4 and 0.032-inch stainless-steel plate after test.

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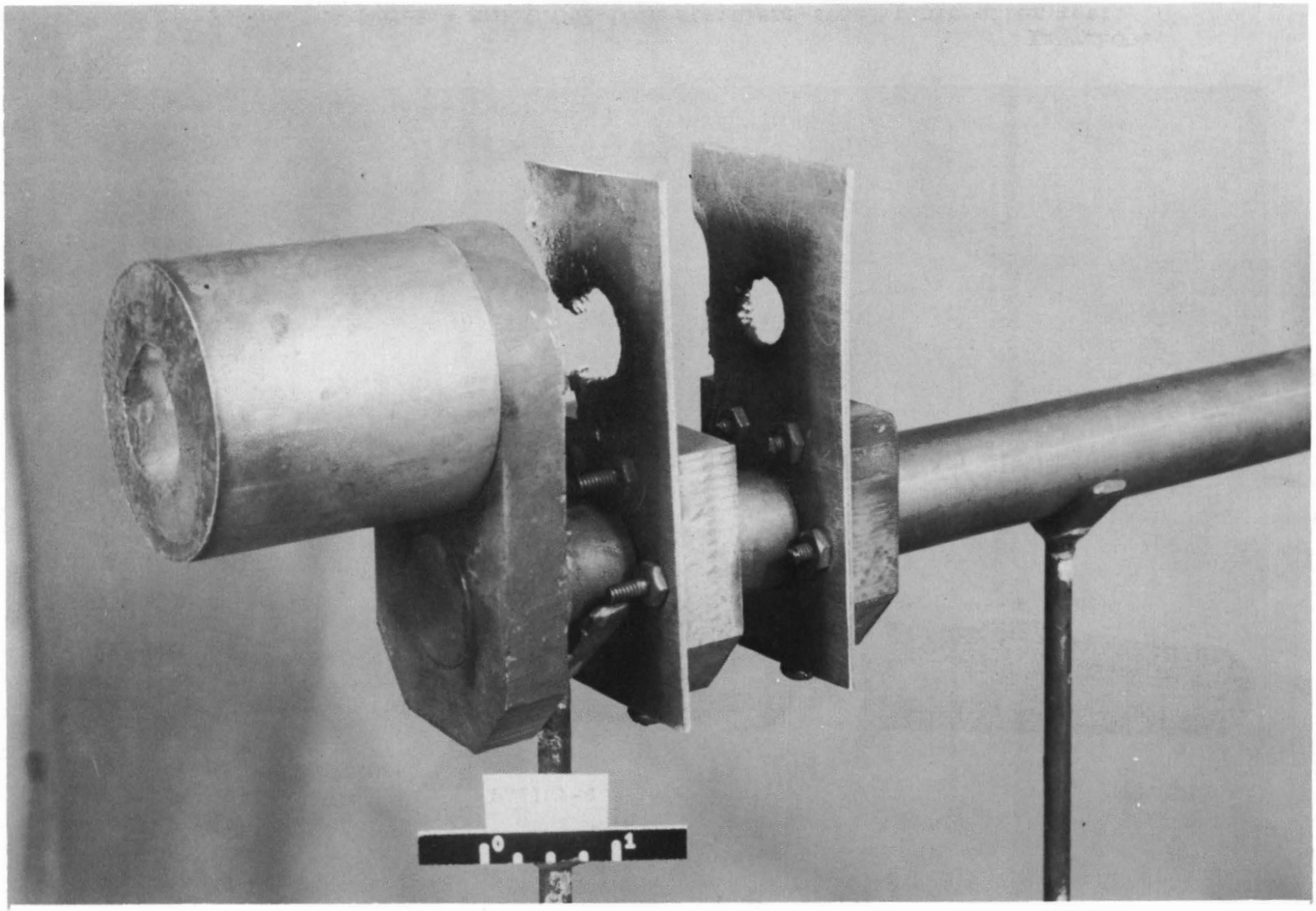

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Figure 10.- Model 5 and 0.061-inch aluminum-alloy plates after test.

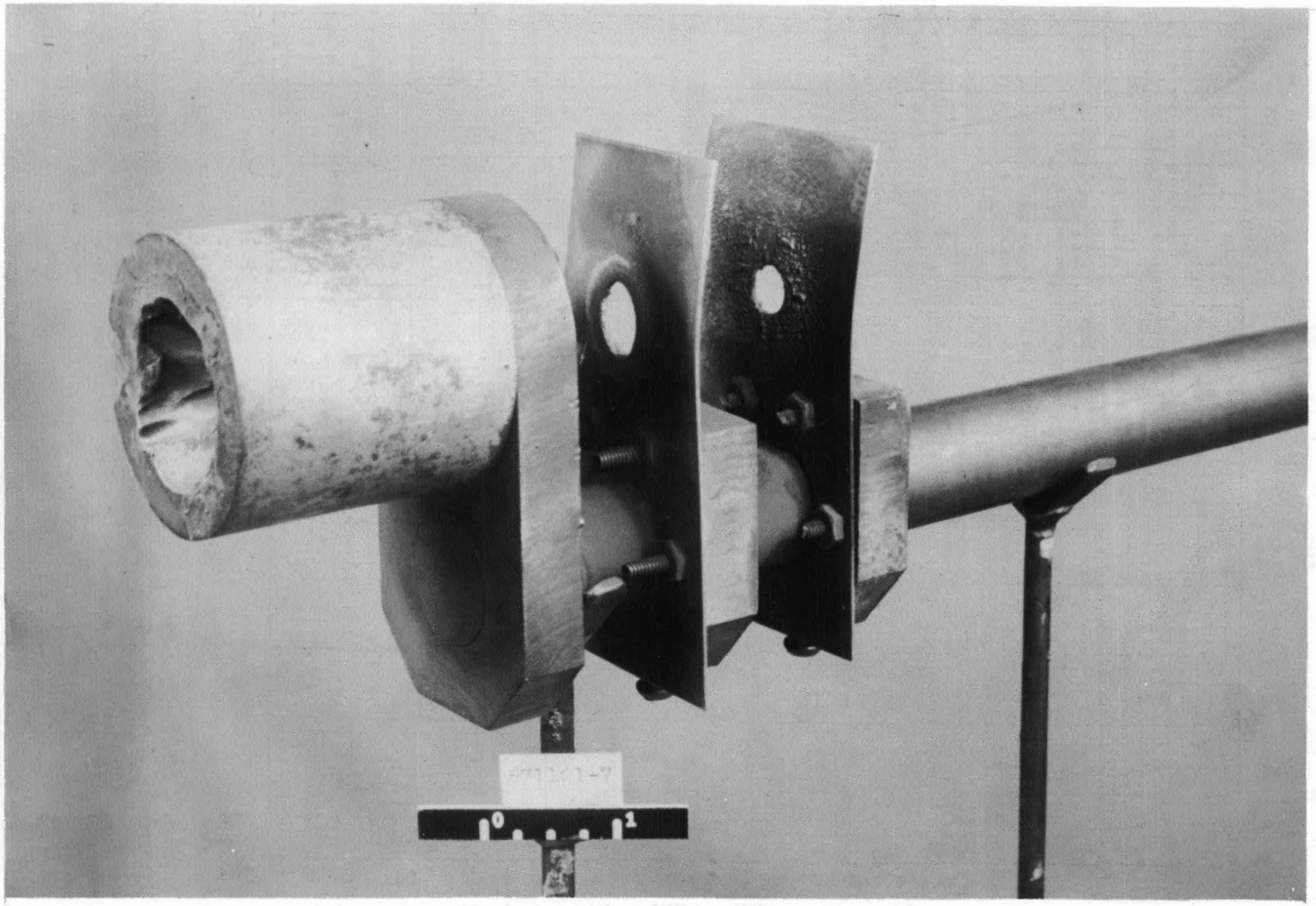

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Figure 11.- Model 6 and 0.032-inch stainless-steel plates after test.

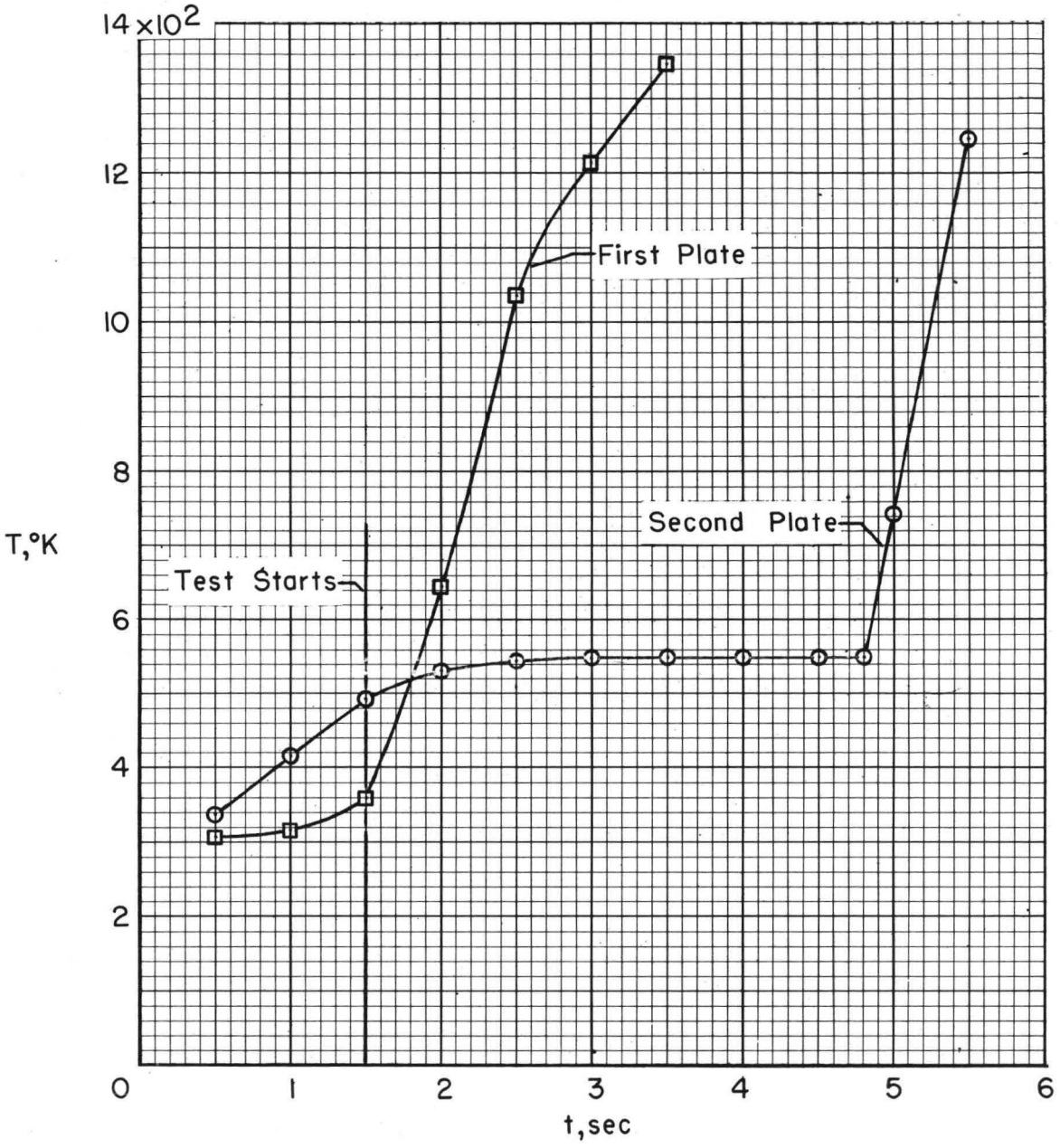

Figure 12.- Time histories of target-plate temperatures for model 6.

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